Abstract

In 1993 a digital mobile telephone system, Global System for Mobile Communications (GSM), was introduced in Australia and will completely replace the older analogue system by the year 2000. Concerns arose that the new system could cause interference to the operation of hearing aids or other electronic devices. This possibility was confirmed by measurements undertaken by Telecom Australia and Australian Hearing Services (AHS). This prompted an extensive investigation by AHS, Telecom, and AUSTEL (the telecommunications' industry regulator) in collaboration with Optus and Vodafone the other providers of *digital mobile telephone* services, the hearing aid industry and consumer representatives. This report presents the methodology and findings of the investigation and makes recommendations for minimising the interference problem.

The primary aims of the study were: (a) to assess the degree of interference caused to a wide range of hearing aids by the operation of a GSM *mobile telephone*; (b) to assess the effectiveness of various treatments and design modifications to hearing aids for reducing GSM interference. Important secondary aims were the development of a reliable and practical measurement system and the development of criteria for hearing aid standards with respect to immunity from GSM interference.

A highly effective measurement system was developed. It consists of a waveguide for generating radio-frequency fields and a manipulator for orienting the hearing aid to detect interference. Measurements were made on a range of behind-the-ear and in-the-ear hearing aids which had varying degrees of susceptibility to GSM interference. This covered virtually the whole range of interference levels likely to occur in currently available hearing aids. Technical measurements were supplemented by subjective tests to determine the distance at which interference (a "buzzing" sound) could be detected by hearing-impaired people wearing appropriately fitted hearing aids. The hearing aids were found to vary from some (high-immunity) models for which no interference was detectable even with the hearing aid within a few centimetres from the telephone, to others (low-immunity) models for which interference was detectable at several metres or more. Interference was least for models with compact designs which minimised the length of microphone leads.

Hearing aid treatments consisted of shielding, i.e. coating the hearing aid case with a conductive material or using metal-impregnated cases, and/or the inclusion of shunt capacitors in the circuit. The effect of the treatments varied from nothing to substantial. The tests show that it is possible and practical to design hearing aids to have high immunity although it may not always be practical to treat existing hearing aids to achieve high immunity. High immunity hearing aids would virtually ensure that the hearing aid wearer would not experience interference from other people's use of GSM *mobile telephones*. However, extremely high immunity is required to enable a hearing aid wearer to use a hand-held GSM telephone. Such immunity is achievable for some hearing aids.

This investigation has elucidated the potential interference problem, has demonstrated that it is possible to design high-immunity hearing aids, has developed a practical measurement system, and has provided data for making realistic recommendations about hearing aid immunity standards and the design and use of *mobile telephones* for minimising the problem of interference to hearing aids.

Contents

Appendices

Tables

Figures

Preface

In the first quarter of 1993, the National Acoustic Laboratories and Telecom Research Laboratories co-operated in a preliminary investigation into the susceptibility of hearing aids to interference from GSM *digital mobile telephones*. It was apparent that more work had to be done to find ways to measure this interference and to make improvements to hearing aids. As a result a technical committee was formed whose membership included representatives of the three mobile carriers, i.e. Telstra, Vodafone and Optus, the Spectrum Management Agency, the Deafness Forum of Australia, AUSTEL and hearing aid suppliers including Australian Hearing Services.

The results of work undertaken by this technical committee and its parent task group are reported herein. It describes measurements of the immunity of hearing aids to interference from digital mobile telephones along with improvements that can be made to increase immunity to an acceptable level.

This report is intended for a wide audience, including hearing aid manufacturers and distributors, members of the telecommunications industry, hearing aid users and user groups and standards organisations. Each chapter contains an introductory synopsis that may be read by the general reader, and the bulk of supporting technical matter appears in the appendices.

The work on hearing aids was undertaken at the National Acoustic Laboratories (NAL) by Ross Le Strange and Eric Burwood. Denis Byrne also at NAL carried out subjective testing on hearing impaired subjects. Ken Joyner and Mike Wood designed and tested the terminated waveguide measuring system at the Telecom Research Laboratories (TRL). Ross Le Strange designed the manipulator used in conjunction with the waveguide. Grant Symons of AUSTEL coordinated the work and liaised with the three mobile carriers who supplied funding. John Hunter provided facilities, advice and assistance in using the radio frequency anechoic room at the National Measurement Laboratories.

Thanks are due to Phonak Australia Pty. Ltd. and Oticon Australia Pty. Ltd. who supplied several hearing aids for testing. Mobile telephones were obtained from Neil Marley and Jonathon Withers of Vodafone and Ken Joyner of TRL.

Acknowledgment

The work described in this report was supported by the mobile telephone carriers, Telstra Corporation Limited, Optus Communications and Vodafone Pty Limited. Together they provided assistance and the bulk of funding for carrying out the work and publishing this report.

1. Introduction

Why does this interference occur and why is it now an issue?

Hearing aids and other electronic equipment are subject to interference from low power mobile transmitters in close proximity when the intensity of the radio wave varies at an audible rate. The continuing increase of personal communications is creating the potential for this interference to become worse in the future. This study covering interference to hearing aids was initiated by several organisations including Telecom Research Laboratories, AUSTEL, the Deafness Forum of Australia, the Spectrum Management Agency, and hearing aid suppliers including Australian Hearing Services.

The emergence of mobile telecommunications in the coming years ensures the need for immunity of hearing aids and other systems to low power ultra high frequency transmitters in close proximity. Methods investigated here will be applicable not only to those required for hearing aids but also to many other systems.

THE INTERFERENCE

The recent introduction of *digital mobile telephones*, with their portability and pulsed transmissions, has created a new class of interference issues. This interference typically presents itself as a buzz in the effected audio electronic equipment. Interference to other equipment is also possible.

In the past incidents of this kind of interference, caused by rectification of radio frequency signals by equipment susceptible to this kind of interference, were the exception, and mostly occurred within general proximity to high powered radio transmitters. However, the increasing ubiquity of small low power *digital mobile telephones* has the potential to make interference from this class of device more prevalent. Even though their radiated power is low, *digital mobile telephones* used in close proximity (i.e. within metres), to other electronic equipment such as hearing aids, may produce greater interference than can much higher powered transmitters at ranges of a few hundred metres.

Telephones used with the established "analogue" mobile system do not, as a rule cause audio rectification type interference since the transmitted envelope is not pulsed and is essentially of constant amplitude.

The introduction of GSM *digital mobile telephones* to Australia prompted the initiatives presented in this report. It is possible that systems exhibiting similar characteristics will follow. Future designs of electronic equipment intended for operation in the new electromagnetic environment must observe new immunity standards, encompassing GSM and its successors, that will control the extent of interference to a level that is acceptable to the community.

This report covers work done to investigate *digital mobile telephone* interference to hearing aids. Recommendations are made on equipment, design guidelines and immunity standards for hearing aids.

BACKGROUND TO THE PRESENT WORK

In the first quarter of 1993, the National Acoustic Laboratories and Telecom Research Laboratories cooperated in a short technical study investigating the susceptibility of some typical hearing aids to interference from digital mobile telephones. The results of the study were presented in a joint report which is reproduced in Appendix 6. The report indicated that some hearing aids tested were significantly immune to interference whilst others could experience interference at ranges up to approximately 30 metres.

It was confirmed that the interference mechanism is intimately associated with the essential nature of the mobile telephone emissions and is not an incidental by-product which might for example, be solved by improved shielding of the telephones. As a result of the initial report, the then Department of Transport and Communications established the *Hearing Aid EMI Task Group* to resolve the issue.

A reporting line for the *Task Group* was established through the *Consultative Working Group on Side Effects of Radio Frequency Emissions* of the Spectrum Management Agency's *Radiocommunications Consultative Council*. *Task Group* members considered that the slow initial expansion of the population of GSM digital mobile telephones (i.e. few potential sources of interference in the short term) would provide a buffer period during which ameliorating solutions could be developed. They recognised that because the average hearing aid has a lifetime of only five years, the issue could be usefully addressed through the normal replacement cycle if suitably hardened hearing aids could be made available within a few years.

The planned strategy would require the development of immunity improvement measures with a standard to quantify immunity and, to these ends, a technical subcommittee reporting to the *Task Group* was created. Its membership included representatives of the three mobile carriers, the Spectrum Management Agency, the Deafness Forum of Australia, AUSTEL, Telecom Research Laboratories and hearing aid suppliers including Australian Hearing Services.

The *technical subcommittee* was charged with finding practicable means for improving the immunity of hearing aids, recommending the basis for a suitable radio frequency immunity standard, finding means for hearing aid users to use GSM *digital mobile telephones* without undue interference, and subjectively evaluating the efficacy of proposed modifications with hearing aid users.

As well as oversighting the work of the technical subcommittee, the *Task Group* organised a series of public presentations, two in Sydney and one in Melbourne, on the nature and extent of interference including practical demonstrations of the interference phenomenon. The sessions were supported by AUSTEL, the Spectrum Management Agency, and the three mobile carriers. Levels of attendance and representation varied, but of the hearing aid users that attended, most appeared satisfied at the improved level of understanding of the issues achieved. The measures being undertaken in response to GSM interference should also provide some protection against other interference sources occasionally encountered by hearing aid users.

Although not central to the focus of this report, other ameliorating initiatives were undertaken. The Mobile Carriers' implementation of *Power Control* and *Discontinuous Transmission*[1] was expected to reduce the average incidence of interference. A recommendation, to be included in the mobile telephone users' handbook and packaging, advising users how to avoid causing interference, was added to the relevant *AUSTEL Technical Standard, TS018.*

THE ELECTROMAGNETIC ENVIRONMENT

Other Systems

As indicated above, the audio rectification phenomenon associated with nearby ultra high frequency (UHF) emissions having varying amplitude, is the fundamental cause of the hearing aid interference problem, a problem not limited to hearing aids.

While the *Task Group* did not specially address the amelioration of interference in equipment other than hearing aids, some of the work pursued may find wider application. In particular, the measurement methodologies developed should be generally applicable to any similarly compact electronic items especially battery powered ones having minimal external electrical wiring. Also, the results of various screening techniques investigated, such as metal filled plastic case mouldings, and sputtered, evaporated, painted and electro-deposited conductive coatings, should be applicable across a wide range of goods.

Screening should generally work where the unwanted radio-frequency emissions are at a comparable frequency to the 900 MHz frequencies studied, and where the principal interference mechanism involves case penetration. Even where the unwanted emission is modulated at a frequency outside the audio range, say ultrasonic, the principles still hold although instrumentation for measuring the

[1] Power Control and Discontinuous Transmission (DTX) are features of GSM developed primarily to minimise power consumption of the *digital mobile telephone* and optimise spectrum utilisation.

demodulated[2] interference would obviously need to suit the particular requirement.

Future Scenarios

Most industry commentators agree that today's mobile cellular networks are just a foretaste of what is to come and that wireless telecommunications will continue to escalate over the next 10 years. It is expected that several digitally based wireless technologies supporting a wide range of services including voice, text and graphics will become generally available in most population centres. While future radiated power levels from mobiles may be less than those commonly required today, their expected ubiquity will ensure the need for minimum levels of electromagnetic immunity in hearing aids and other electronic equipment liable to be affected.

The Spectrum Management Agency, in recognition of our increasingly complex electromagnetic environment, is setting up an Electromagnetic Compatibility (EMC) framework for Australia. The Spectrum Management Agency's strategy is first to adopt a mandatory emissions regime through product standards, or where none exist, through a generic emission standard. Emissions standards will be complemented by a generic immunity standard applying to any product with potential or recognised, susceptibility. The generic standard will apply until appropriate product specific immunity standards are adopted. The Australian Standard for hearing aid immunity emerging from the work reported here is such a product specific standard.

The emphasis in the work undertaken, to date has been on disturbances arising from radio frequency energy in the 900 MHz region. It is expected that the next generation of systems referred to will operate, predominantly in the 1800 to 2200 MHz region. The emissions will thus have appreciably shorter wavelengths than those studied in conjunction with GSM *mobile telephones* and the immunity performance of affected hearing aids towards them may be significantly different. The performance of the various screening methods investigated is also likely to be different and the detail of the test instrumentation, particularly the detailed design of the waveguide test apparatus needs modification for these higher frequencies.

With the continued emergence of mobile telecommunications in the coming years and with wireless connectivity modes, including wide-band communications, expected to become the norm rather than the exception, the need for immunity in hearing aids and other systems will be greater than ever.

---

[2] "Demodulation" is any process for recovering "information" from a radio frequency signal. "Rectification" is one such process and here we are concerned with unwanted "information".

THE REPORT

This account is based on the interference to hearing aids from the use of *Two watt Hand-Held GSM digital mobile telephones*[3], which are licensed for use in Australia.

Chapter 2 summarises the physical measurements of hearing aids undertaken to show the important parameters that characterise a hearing aid in respect of this interference. Evidence is presented to show how the immunity may be improved.

How this interference affects hearing aid users is the subject of Chapter 3 which describes the subjective measurements undertaken during the study. They are presented in two parts. Early in the study hearing impaired subjects were exposed to interference from *mobile telephones* to assess some of the problems and distances at which interference became apparent. After the physical measurements of hearing aids were complete, a set of hearing aids that covered a wide range of immunity to interference was available. This set was used to assess the amount of perceived interference by persons with normal hearing, as a function of the level of immunity.

An interpretation of these measurements is given in Chapter 4 where immunity specifications are developed. The findings are brought together in the summary and recommendations of Chapter 5 at the end of the body of the report.

Appendices contain technical information considered too detailed for inclusion in the body of the report. A considerable amount of supporting material gives details of test equipment and methods, the detection of radio frequency signals and background information on draft standards for hearing aids.

---

[3] This report concentrates on the "hand-held cellular mobile station" meaning a complete GSM telephone designed to be held in the hand and may be termed a *hand-held digital telephone*. A "Transportable cellular mobile station" is a mobile station containing a radio frequency transmitter and receiver in one unit and acoustic transmitter and receiver transducers in a separate handset connected to the first unit by cable. The radio frequency transmitter and receiver unit may be termed the *Transceiver*, and the acoustic transmitter and receiver transducer unit the *Handset*. Unless otherwise indicated the term ***mobile telephone*** is used in this report for a *2 watt hand-held digital telephone*.

2. Physical Measurement of Hearing Aids

Measurements of GSM interference were made on five behind-the-ear (BTE) hearing aid models and on two in-the-ear (ITE) models, for microphone and for telecoil inputs. Measurements were also made of the effects of various treatments designed to increase hearing aid immunity to GSM interference. This chapter presents: (a) a discussion of the measurement strategy, (b) a description of the measurement methods, (c) an explanation of how the measurement data should be interpreted, (d) the results and (e) a discussion of the results. The hearing aids showed a very wide range of immunity levels, that is, of their susceptibility to picking up interference from GSM transmissions. The several types of treatments that were tested improved immunity levels by various degrees. It was found that it is possible to design or treat both BTE and ITE hearing aid types to achieve high immunity levels. Effective means of treatment are summarised in the Conclusions section of the chapter.

MEASUREMENT STRATEGY

Background

Preliminary measurements[2] using GSM *mobile telephones* indicated that large interfering signals could be received by a hearing aid when it was close to a transmitting GSM *mobile telephone*. In order to quantify the interference, preliminary tests were made, first with a microwave resonator in conjunction with a standard laboratory signal generator, and then with a quarter wave antenna in a corner reflector. The resonator produced very high radio fields but was very difficult to use. The corner reflector gave sufficient field strength to interfere with hearing aids of low immunity, but not enough for those with higher immunity. Also accurate measurements were made difficult by the disturbances to the field by the presence of the operator and reflections in the surrounding room. Both have the disadvantage that the field is non-uniform and difficult to calibrate. It became apparent that special apparatus was necessary to obtain a constant and relatively uniform field, and to manipulate the hearing aid in this field.

These problems and the fact that illegal radiation must be avoided, led to the design and construction of a terminated waveguide and a special manipulator simulating gimbals for positioning the hearing aid inside the waveguide. This enabled reliable measurements to be undertaken and the interference to be studied more carefully.

Sensitivity to Electromagnetic Fields

When a hearing aid is placed in a radio frequency field, such as that surrounding a *mobile telephone* during transmission, voltages at radio frequencies are induced on the conductive paths connected to the input of the hearing aid amplifier. GSM *mobile telephones* use a radio frequency carrier in the 890 to 915 MHz region. When considering the interference caused, it can be treated as bursts of radio frequency energy at a rate of 217 pulses per second. The length of each burst (or pulse) is one eighth of the period, i.e. 0.6 millisecond. Relatively high field strengths are produced near these *mobile telephones*. Amplitude variations (i.e. amplitude modulation) of the radio frequency field are said to be "detected", i.e. they are rectified by the amplifier input transistor and appear in the acoustic output of the hearing aid where they may be heard loudly enough to be annoying and to interfere with hearing aid use. Detection is discussed in Appendix 4, where it is shown how audio frequency voltages of comparable magnitude to those produced by the microphone can be produced by "unsuppressed" amplitude modulated radio frequency voltages. The result is a characteristic buzzing sound in the hearing aid.

Objective

The interference problem is caused by the introduction of pulsed radio frequency fields into the "electromagnetic environment" by *digital mobile telephones*. The close proximity (i.e. from a few centimetres to several metres) is the reason for the high field strength that can cause the interference, even though the total radiated power is small.

The purpose of the investigations undertaken was to:

- characterise and quantify the sensitivity of hearing aids to the interference,
- demonstrate realistic methods of measurement,
- make a more realistic assessment of the possible effects,
- explore solutions that are appropriate for the design of hearing aids, and
- propose immunity standards for new hearing aids.

Criteria

It is desirable to measure the detected interference as directly as possible. The effects of changeable and subjective factors can be derived from the measurements of the underlying cause; and can be taken into account as needed. Important variable factors that arise are:

- *The level of radio frequency signal affecting the hearing aid:* The magnitude of the radio frequency voltage induced in the hearing aid circuits depends on:
    - the attitude of the hearing aid in space relative to the incident radio frequency wave,
    - the effect of the head and other surrounding objects in shielding, reflecting or absorbing radio frequency energy,
    - the distance between the hearing aid and the transmitting *mobile telephone* and
    - the amount of power radiated.
- *The frequency response of a hearing aid:* This depends on its design and adjustment and has the effect of changing the spectrum and magnitude of the acoustic output caused by the interference.
- *The effect on the hearing aid wearer:* This depends on his or her particular hearing loss; the perception of the interference is subjective.

Physical Measurements

Measurement of the detection, or "reception" of audio frequency interference is required together with a subjective evaluation of the effects to enable the measurements to be interpreted realistically. Satisfactory specifications for hearing aids may then be proposed with more confidence.

The measurements of the interference to hearing aids described in this chapter were undertaken to:

- measure the physical mechanism linking the radio frequency wave and the detected signal in the hearing aid in relation to the relevant acoustic sound pressures for microphone input and relevant magnetic field strengths for telecoil input,
- allow for the attitude of the hearing aid relative to the incident radio wave in a simple way,
- be invariant to the frequency response of the hearing aid,
- eliminate any subjective interpretation,
- be repeatable and easily replicated at other laboratories, and
- use readily available equipment and procedures as much as possible.

DESCRIPTION OF THE MEASUREMENTS

Radio Frequency Field

Waveguide

A waveguide test system that covers the GSM radio frequency band was designed, constructed and tested. The design of the waveguide test system is described in Appendix 1. It was used to generate a radio frequency field into which the hearing aid could be placed. A special manipulator using gimbals was designed to align the hearing aid inside the waveguide for maximum response to the radio field.

Appendices 1 and 2, sets out details of the measurement apparatus, techniques and precautions taken.

Modulation of the radio frequency field

In the measurements reported here, a 900 MHz carrier was 80% amplitude modulated by a 1000 Hz sine wave. The field strength quoted is for the unmodulated carrier. Sinusoidal modulation was chosen as the simplest way to most directly measure the "detection" at the input of the hearing aid. A narrow band filter (one third octave) was used to remove unwanted noise. The frequency response of the hearing aid does not affect the measurements.[4] With the equipment used, carrier field strengths up to 200 volt per metre could be generated in the waveguide with the 80% amplitude modulation applied to give a peak field strength[5] of 360 volt per metre RMS.

Acoustic Measurement

The acoustic output of the hearing aid was coupled to a standard 2 cc coupler (AS1809, IEC126) via a 500 mm length of plastic (Tygon©) tube, except for a short piece of metal tubing where it entered the waveguide. The hearing aid acoustic output was measured using a one third octave filter at 1000 Hz and was converted to an *equivalent input referred sound pressure*[6] that would produce the same acoustic output in the hearing aid by subtracting the acoustic gain in dB at 1000 Hz. This *equivalent input referred sound pressure* allows comparison of hearing

---

[4] The spectrum of the GSM interference in the output of the hearing aid is not considered to be important; refer to Chapter 4.

[5] This is the RMS value over one radio frequency cycle at the peak of the one kilohertz modulation, i.e. a peak radio field strength of 509 volt per metre.

[6] This is later referred to *equivalent detected input referred sound pressure* to emphasise that it is caused by *square law rectification* (or *detection*) at the amplifier input.

aids independently of their acoustic gain, and direct comparison with the environmental sound fields in which the hearing aid is used.

When the hearing aid was switched to telecoil input, the measured hearing aid acoustic output was converted to an *equivalent input referred magnetic field strength*, i.e. the magnetic field strength that would produce the same acoustic output in the hearing aid at 1000 Hz.

Test Procedure

The acoustic gain of the hearing aid and the magnetic sensitivity for telecoil if required, were measured at 1000 Hz.

The hearing aid was fixed in the holder of the manipulator, placed in the waveguide and the attitude of the aid was adjusted for maximum pickup. While this was being carried out, the radio frequency field strength was adjusted as necessary to maintain the output of the hearing aid below saturation and above the noise level. None of the hearing aids measured had any signal processing that interfered with their linear operation.[7]

Under computer control, the radio frequency field strength was stepped from low to high values over a range that caused the hearing aid output to respond in the region between the noise level and saturation[8]. The output was amplified, filtered to reduce noise to low levels, measured and graphed as *equivalent input referred sound pressure* (or *magnetic field strength*)[9] as a function of the radio frequency field strength.

---

[7] In the case of hearing aids using signal processing, special care and techniques may be necessary to avoid error. A simple example of signal processing that may cause problems is provided by hearing aids fitted with simple compression that operates at normal speech levels to cause the acoustic gain to vary with time.

[8] In almost all cases the range spanned the whole dynamic range of the hearing aid.

[9] This is the magnetic field strength varying at audio frequencies used to drive the hearing aid telecoil. The telecoil is used instead of the microphone to magnetically couple into a telephone or an induction loop system.

INTERPRETATION OF THE MEASUREMENTS

Measurements

A typical measurement of a hearing aid is shown in Figure 1. A square law response to the magnitude of the electric field of the radio frequency field is exhibited and is shown by the straight part of the curve with a slope of 2, i.e. a 1 dB increase in radio frequency field strength causes a 2 dB increase in hearing aid output. A theoretical discussion is found in Appendix 4, where it also gives the relationship between the sinusoidal amplitude modulation used in testing and pulsed amplitude modulation equivalent to the emissions from GSM *mobile telephones*. The bottom scale shows the corresponding field strengths with GSM emissions for comparison.

Figure 2 illustrates the wide range of hearing aid responses to an amplitude modulated 900 MHz radio signal that were measured.

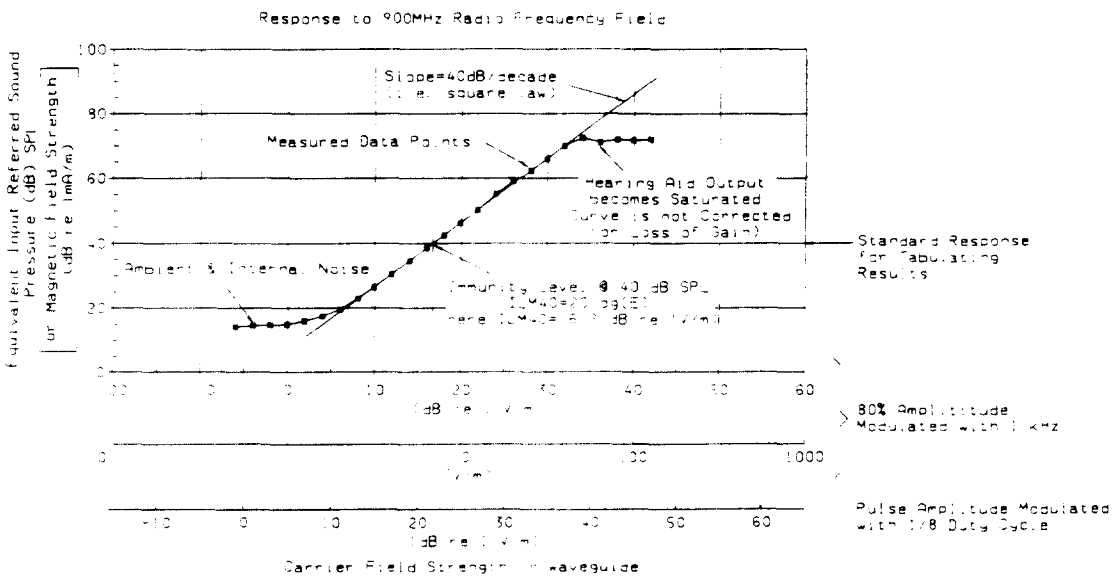

Figure 1 Details of a Hearing Aid Measurement in a Radio Frequency Field

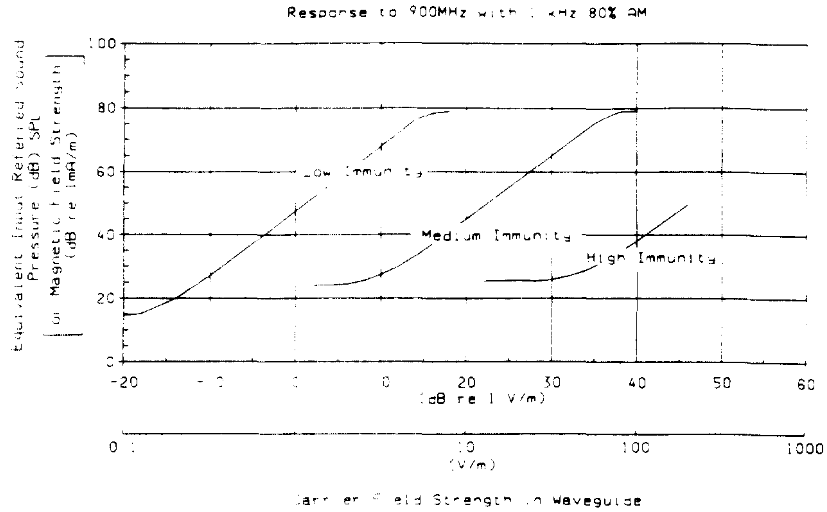

Figure 2 Range of Observed Hearing Aid Measurements in a Radio Frequency Field

Immunity Level

The susceptibility of a hearing aid to interference may be measured by the electric field strength that produces a *standard response* in the hearing aid. Given a suitable definition of the standard response, this field strength can be interpreted as a measure of the immunity of a hearing aid.

The *standard response* or *reference level* is chosen to be an input referred sound pressure that intercepts the linear part of all the measured responses, see Figure 1. A reference level of 40 dB SPL has been chosen for this report. This reduces each measured response to a *single number*, namely the field strength producing the reference level in the hearing aid. In this report the field strength is quoted in decibels relative to 1 volt per metre, reflecting the wide range to be covered and is called the *Immunity Level*. An *Immunity Level* may be defined not only for the case when the hearing aid is switched for microphone input but also when it is switched for telecoil input.

Definition of Immunity Levels

Microphone Input: The *immunity level* (ILM40), is the carrier field strength in decibels relative to one volt per metre (dB re 1 V/m) that produces a response in the hearing aid equivalent to a 1000 Hz *input referred sound pressure* equal to 40 dB SPL, when the carrier is 80% amplitude modulated at 1000 Hz.

Telecoil Input: The *immunity level* (ILT20), is the carrier field strength in decibels relative to one volt per metre (dB re 1 V/m) that produces a response in the hearing aid equivalent to a 1000 Hz *input referred magnetic field strength* equal to 20 dB relative to 1 mA/m, when the carrier is 80% amplitude modulated at 1000 Hz.

These definitions are used for reporting purposes only. Recommendations are made in the summary, chapter 5 in relation to standards and specifications for hearing aids.

Treatments

Hearing aids were subjected to treatments expected to improve immunity to interference. An improvement is indicated by an increase in *immunity level*. Measurements showing such an improvement are illustrated in Figure 3. A horizontal shift of the measured curve to the right, (measured in dB re 1 V/m) indicates that a higher field can be tolerated for the same level of interference. Improvements obtained with more than one treatment are multiplicative on the scale of field strength so that improvements in *immunity levels* are additive.

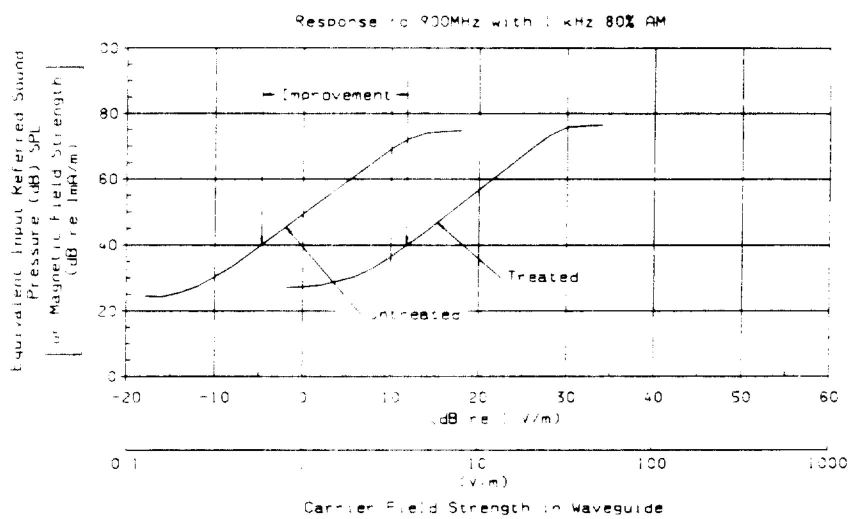

Figure 3 Hearing Aid Measurements Before & After Treatment

RESULTS

Hearing Aids

Descriptions of the hearing aids tested are shown in Appendix 2. The types are shown in the tables as:

- HP BTE High power Behind-the-Ear hearing aids,
- MP BTE Medium power Behind-the-Ear hearing aids, and
- ITE In-the-Ear hearing aids.

They are considered to be representative of current hearing aids in general use.

Treatments

The *immunity levels* are tabulated for hearing aids:

- Untreated,
- treated with various methods for electrostatic shielding,
- fitted with case parts moulded with metal filling, and
- fitted with shunt capacitors.

Immunity levels are given for both microphone, and telecoil inputs where these were measured.

Tables

The *immunity levels* measured for the untreated hearing aids are shown in the first two tables.

The following tables show improvements in *immunity levels* for *individual hearing aids* subjected to the specified *treatment*. The *improvements* obtained ranged from -4 dB to +34 dB.

Untreated Hearing Aids

Table 1 and Table 2 list the measured sensitivities with microphone and telecoil respectively for the range of hearing aids tested. It can be seen that the *immunity levels* vary over a wide range from one with virtually no immunity (ILM40 < -3) to one that can almost be used for communication with a *mobile telephone* (ILM40 > 30). The values for telecoil inputs show an even wider range in *immunity levels*.

Table 1 Untreated Hearing Aids, Microphone Input

Hearing Aid				*Field Strength for 40 dB Input Referred SPL (V/m)*		*Immunity Level (dB re 1V/m)*
Type	*Manufacturer*	*Model*	*No. of Samples*	*Spread*§ *(from - to)*	*Average*	*ILM40 (Average)*
HP BTE	Phonak	PPCL4	3	2.11 – 3.19	2.46	**7.8**
	Bernafon NAL	SP675	3	12.6 - 17.3	15.9	**24.0**
MP BTE	Calaid	VHK	6	0.63 - 0.75	0.70	**-3.1**
	Oticon	425	1	-	3.4	**10.5**
	Bernafon NAL	SB13	3	3.5 - 6.9	5.8	**15.3**
ITE	Phonak	9000AFS	2	2.0 - 14.4	8.7	**18.8**
	Bernafon NAL	IT312	5	23.9 - 37.7	32.4	**30.2**

§ This is the spread of results for this test only. Other samples used in further testing fall outside this spread of results.

Table 2 Untreated Hearing Aids, Telecoil Input

Hearing Aid				*Field Strength for 10 mA/m Input Referred Magnetic Field Strength (V/m)*		*Immunity Level (dB re 1V/m)*
Type	*Manufacturer*	*Model*	*No. of Samples*	*Spread (from - to)*	*Average*	*ILT20 (Average)*
HP BTE	Bernafon NAL	SP675	3	90.1 - 161.6	115.6	**41.3**
MP BTE	Calaid	VHK	3	1.17 - 1.75	1.37	**2.7**
	Bernafon NAL	SB13	3	348 - 521†	427	**52.6**

† The values for the last hearing aid are extrapolated from values at 200 V/m.

Electrostatic Shielding

Electrostatic shielding was expected to be an effective way of making hearing aids to be less sensitive to interference. Several experimental methods were used to make a conducting film around the hearing aid amplifier: silver paint, sputtered silver, electroless nickel plating and a decorative metal coating.

Silver Based Electrically Conductive Paint

Table 3 shows improvements observed when a conductive (silver paint) coating was brushed on to the cases of some of the hearing aids. The measured values for each sample treated are listed and show the variations that were typically observed. Improvements in shielding of around 20 dB (referred to the radio frequency field strength) were readily obtained and over 30 dB in one case. When the case was only partly shielded the improvement was much less. No attempt was made to make electrical connection between the conductive coating and the amplifier. Care was taken to ensure a low resistance continuous coating on the case.

Table 3 Electrostatically Shielded with Silver Paint, Microphone Input

Hearing Aid				*Immunity Level ILM40 (dB re 1 V/m)*		
Type	*Manufacturer*	*Model*	*Treatment*§	*No Shielding*	*With Shielding*	*Improvement*
HP BTE	Phonak	PPCL4	Coat outside all over	6.8	36.2	**29.4**
				10.2	34.5	**24.3**
				6.8	41.0	**34.2**
	Bernafon NAL	SP675		20.1	41.1	**21.0**
				19.2	40.4	**21.2**
MP BTE	Calaid	VHK		-9.0‡	13.1	**22.1**
	Bernafon NAL	SB13	Coat inside of two case sides only, the top side being uncoated	11.9	19.5	**7.6**
				11.2	16.4	**5.2**
ITE	Bernafon NAL	IT312	Coat outside all over including shell	29.5	48.1†	**18.6**
				31.5	49.3†	**17.8**
				27.6	47.9†	**20.3**
				30.4	49.9†	**19.5**

§ The coatings were not complete being broken around the controls, battery compartment and acoustic ports.
† These values are extrapolated from values up to 200 V/m.
‡ This particular aid was less immune that aids previously tested.